TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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A ROADMAP TOWARDS AGILITY FOR FINNISH MANUFACTURING COMPANIES

Master of Science Thesis

Examiners: Assoc. Prof. Minna Lanz and Dr. Eeva Järvenpää

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ABSTRACT

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Companies have to deal with continuous and unpredictable changes in today’s challenging business environment. Agility means a capability of a company to react rapidly and efficiently to changes. The objective of this thesis is to create a roadmap, which helps Finnish manufacturing companies to identify and prioritize actions that are needed in order to improve their agility.

The thesis is divided into two parts: theoretical part and empirical part. The theoretical part consists of literature review, which presents concepts and models related to agility. The purpose of the literature review is to identify tools, practices and characteristics that enable agility in a manufacturing company. The identified enablers of agility are utilized in the empirical part of the thesis, as challenges related to agility are investigated.

The empirical part of the thesis focus on analysing challenges that Finnish manufacturing companies have related to agility, and proposing actions for solving these challenges. Interviews conducted among 25 Finnish manufacturing companies operating in machine building industry, were utilized to collect challenges and needs regarding production planning and control. Based on the conducted interviews, altogether 50 challenges affecting agility were identified. Most of the interviewed companies are not using correct IT-systems in production planning and control to support rapid reactions to changes. Furthermore, the usage of paper documents in data collection from the factory floor, and the lack of systematics in recording different type of deviations are causing several problems. Due to these challenges, information of change situations is not transferred to all factors in real time. Based on the conducted cause-effect analysis, the above mentioned challenges are critical to be solved in order to increase agility among the interviewed companies. For solving challenges, 13 practical actions were proposed. The most important actions for the critical challenges include implementation of new manufacturing IT-systems, increasing automatic data collection, and bringing needed information to production workers in digital format.

As main results of this thesis, two visualized maps are introduced. The relationships map presents the interconnections between the identified challenges. It can be utilized in identifying how different problems are generated and what kind of consequences they have. The action map presents practical actions for solving identified challenges. It guides manufacturing companies in evaluating the importance of different actions that can be implemented in order to improve agility. Together these two maps serve as roadmaps for Finnish manufacturing companies towards agility.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Konetekniikan koulutusohjelma
EEMELI LAMMERVO: Tiekartta ketteryyteen suomalaisille valmistavan teollisuuden yrityksille
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Yritykset joutuvat kohtaamaan jatkuvia ja yllättäviä muutoksia nykypäivän haastavassa toimintaympäristössä. Ketteryydellä kuvataan yrityksen kykyä reagoida nopeasti ja tehokkaasti muutoksiin. Diplomityön tavoitteena on luoda tiekartta, joka auttaa suomalaisia valmistavan teollisuuden yrityksiä tunnistamaan ja priorisoimaan toimenpiteitä, joilla yrityksen ketteryyttä voidaan parantaa. Tutkimus jakautuu kahteen osaan: teoriaosuuteen ja empiiriseen osuuteen.

Teoriaosuudessa suoritetaan kirjallisuustutkimus, jossa esitellään ketteryyteen liittyviä konsepteja ja malleja. Kirjallisuustutkimuksen tavoitteena on tunnistaa työkaluja, käytäntöjä ja ominaisuuksia, jotka mahdollistavat ketteryyden rakentamisen valmistavan teollisuuden yritykseen. Tunnistettuja ketteryyden mahdollistajia hyödynnetään työn empiirisessä osuudessa, kun tarkastellaan ketteryyteen liittyviä haasteita.

Tutkimuksen empiirisessä osassa keskitytään analysoimaan ketteryyteen liittyviä erinäisiä haasteita, joita kävi ilmi suomalaisen valmistavan teollisuuden piirissä suoritettujen yrityshaastattelujen pohjalta. Haastatteluiden kohderyhmänä oli 25 suomalaista konepajateollisuuden yritystä, joilta selvitettiin tuotannonsuunnitteluun ja –ohjaukseen liittyviä haasteita ja tarpeita. Haastatteluiden tulosten perusteella tunnistettiin 50 ketteryyteen vaikuttavaa haastetta. Suurin osa yrityksistä käyttää tuotannonsuunnitteluun ja-ohjaukseen tietojärjestelmiä, jotka eivät tue nopeaa reagointia muutostilanteisiin. Lisäksi paperidokumenttien käyttö tiedonkeruussa tuotannon lattiatasolta, sekä systemaattisuuden puute erilaisten poikkeamien kirjaamisessa aiheuttavat moninaisia ongelmia. Näiden haasteiden myötä tieto muutostilanteista ei välity reaaliajassa tarvittaville osapuolille. Haasteiden välisten syy-seuraus suhteiden analysoinnin myötä todettiin, että edellä mainitut haasteet ovat kriittisiä ratkaistaviksi, kun halutaan parantaa haastateltujen yritysten ketteryyttä. Haasteiden poistamiseksi ehdotettiin 13 käytännöllistä toimenpidettä. Tärkeimpinä toimenpiteinä kriittisten ongelmien poistamiseksi ehdotettiin uusien tuotannon tietojärjestelmien implementointia ja automaattisen tiedonkeruun lisäämistä tuotannon lattiatasolta. Lisäksi tuotantotyöntekijän tarvitsema informaatio tulisi tarjota tälle digitaalisessa muodossa.

Diplomityön tuloksena esitellään kaksi visuaalista karttaa. Ketteryyteen liittyvien haasteiden välisten yhteyksien tarkasteluun luotiin relaatiokartta, jonka avulla yritykset voivat havainnoida miten erilaiset haasteet syntyvät ja miten haasteet vaikuttavat toisiinsa. Toimenpidekartta puolestaan esittää ehdotettuja toimenpiteitä tunnistettujen haasteiden ratkaisemiseksi. Sen avulla yritykset pystyvät arvioimaan eri toimenpiteiden tärkeyttä. Yhdessä nämä kaksi karttaa toimivat tiekarttoina ketteryyteen suomalaisille valmistavan teollisuuden yrityksille.

PREFACE

When I applied for this Master’s Thesis position nine months ago, I had only a little idea about the topic and content of the work. Working as a research assistant in Lean-MES-project at the Department of Mechanical Engineering and Industrial Systems has been an interesting and challenging journey. I have learned a lot of new things during this work. At first, the objective of my thesis was quite unclear, and it felt difficult to progress with writing. However, little by little the big picture started to form and finally I managed to pull everything together.

I would like to thank my supervisors Associate Professor Minna Lanz and Dr. Eeva Järvenpää for providing me outstanding supervision during the whole thesis project. They were always supporting me and helping to steer the work to the right direction. I am also grateful for my working colleagues Ville Toivonen and Changizi Alireza for motivating me through the hard times. Finally, I want to thank my friends and family for their valuable support during my studies.

Tampere, 20th of May 2015

Eemeli Lammervo

ABBREVIATIONS

APS	Advanced Planning and Scheduling
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CE	Concurrent Engineering
CNC	Computer Numerically Controlled
ERP	Enterprise Resource Planning
JIT	Just-In-Time
KPI	Key Performance Indicator
MES	Manufacturing Execution System
MOM	Manufacturing Operations Management
OEM	Original Equipment Manufacturer
RMS	Reconfigurable Manufacturing System
SCP	Supply Chain Planning
SME	Small and Medium-sized Enterprise
TPS	Toyota Production System
WIP	Work-in-process

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1. INTRODUCTION

1.1 Background

The turbulent environment has become the new reality, in which manufacturing companies have to continuously face challenges such as volatile customer demand, short product life cycles and increased product variety and complexity (Monauni & Foschiani 2014). Surviving through turbulent situations demands essential capabilities from companies to learn to understand their changing environments and respond in a proper way to changes. Having the ability to cope with changes is still not enough, as the emphasis should also be on taking advantage of changes as opportunities. Therefore, a concept called agility can be promoted as the solution to companies for maintaining competitive advantage under continuously changing business environment. (Sharifi & Zhang 2001)

Manufacturing companies possessing great agility can respond really fast and efficiently to changes, while maintaining high quality and operating profitably. Agility in operations goes beyond ensuring business continuity; it also deals with exploiting opportunities and building resilience to daily disturbances. Through agile operations, companies are in better position to prevent possible disturbances. To execute with agility, new operational methods, capabilities and mindsets need to be developed. The pursuit of Lean manufacturing by means of systematically removing inefficiencies from manufacturing operations still remains an important supporting factor for agility. (Manyika et al. 2012)

The need for greater agility is clearly recognised in Finnish industry. This came clear in 2011 when an internet survey about change forces affecting Finnish industry was conducted as a part of FOFFI - “Research Agenda for Re-newing the Finnish Manufacturing Technology Industry” project. Experts from research and education organisations named *“the agility and flexibility requirements caused by the operational environment”* as the most influential change force. (Parhaat tuottavat 2011)

1.2 LeanMES-project

This thesis is part of a national LeanMES-project which is one of the six projects running under Finnish Metals and Engineering Competence Cluster (FIMECC)’s MANU-program. The overall goal of the MANU-program is to increase competitiveness of the Finnish manufacturing industry by means of digitalization. LeanMES-project’s goal is to provide lean, scalable and extendable concept for new type of Manufacturing Execution System (MES) that supports the human operator in a dynamically changing environment. The project started in the fall 2013 and will continue until the end of 2017.

The Department of Mechanical Engineering and Industrial Systems (MEI) from Tampere University of Technology (TUT) has been involved in LeanMES-project since the beginning.

The thesis focuses mainly on analysing the outcomes of the company interviews performed at the early phase of the project during the fall 2013 and spring 2014. The interviews were conducted among 25 Finnish manufacturing companies, and the goal was to find out the current level, challenges and needs related to manufacturing operations management practices and tools.

1.3 Research objectives and questions

The overall objective of this thesis is to create a roadmap, which helps Finnish manufacturing companies to identify and prioritize actions that are needed in order to improve agility. The roadmap should provide a holistic view of the problem field, which consists of different kind of challenges hindering agility from manufacturing operations management perspective. In order to achieve the overall objective, the following sub-objectives are set.

The first sub-objective is to investigate the enablers of agility from a manufacturing company point of view by reviewing the existing literature in the field of agility. The aim is to find practices, characteristics and tools that can be utilized in improving manufacturing company's agility.

The second sub-objective is to identify challenges that Finnish manufacturing companies are currently having related to agility. This objective is achieved by utilizing the collected enablers of agility from literature, and a qualitative interview material, which was generated by conducting one interview round among 25 Finnish manufacturing companies.

The third sub-objective is to find out the most critical challenges hindering agility in Finnish manufacturing companies, and to propose actions for solving challenges. This objective is achieved by defining interconnections between challenges with cause-effect analysis.

Resulting from these research objectives, three research questions are formulated as follows:

1. What kind of practices, characteristics and tools can be used as enablers of agility for manufacturing companies?
2. What challenges Finnish manufacturing companies have related to agility?
3. What challenges are the most critical ones to be solved in order to improve agility?

1.4 Limitations

A couple of issues are setting limitations for this thesis. Firstly, the company interviews focused mainly on finding challenges regarding the manufacturing operations management practices and tools. Therefore, only those challenges that emerged from the interviews are investigated. That, in turn, limits the possibilities to find an inclusive answer to the second research question, since limited amount of valid information is available. Secondly, the group of interviewed manufacturing companies is limited to Original Equipment Manufacturers (OEM) and sub-contracting companies operating in machine building industry.

1.5 Structure of the thesis

The thesis is structured as follows. In chapter 2, a literature review is performed to build a theoretical foundation for the thesis. The first parts of the literature review focus on introducing the origin of agile manufacturing and providing an overview of definitions related to agility. Then conceptual models related to agile manufacturing and agile supply chain are reviewed. After that, Lean manufacturing elements that can be utilized in supporting agility, are presented. Finally, the last part introduces two types of manufacturing IT-systems that can enable agility.

Chapter 3 introduces the research methodology used in the thesis. The first part of this chapter provides information on how qualitative data was collected by conducting company interviews. The second part presents the selection of interview questions for analysis, and introduces the methods used for analysing the data.

Chapter 4 is dedicated to results of the thesis. First, collected challenges hindering agility in Finnish manufacturing companies are introduced. Then interconnections between the challenges are presented in visualized relationships map. After that, effects of critical root cause challenges are presented and discussed. The last part of the chapter focuses on presenting actions that are proposed for solving the identified challenges.

Finally, the achieved results are discussed and evaluated against the set objectives in chapter 5, as conclusions are drawn.

2. AGILITY OF MANUFACTURING OPERATIONS

In this section a theoretical foundation for the thesis is built. Chapter 2.1 briefly introduces the origin of agile manufacturing concept by explaining how the concept was coined. Chapter 2.2 then gives an overview of various definitions related to agility and other concepts dealing with changeability. Chapter 2.3, which is the broadest part of the section, reviews conceptual models of agile manufacturing and elements of an agile supply chain. In chapter 2.4, the Lean manufacturing elements supporting agility are presented. Finally, chapter 2.5 introduces two types of manufacturing IT-systems that can be used to support agility.

2.1 Origin of agile manufacturing

Agile manufacturing concept was first introduced in 1991 at the Iacocca Institute at Lehigh University in USA. More than 150 industry executives were taking part in a study dealing with US industrial competitiveness. The main goal was to formulate a new paradigm helping manufacturing companies to survive in the 21st century. It was found out that competitive advantage can be determined by new criteria of quality and customer satisfaction. Critical manufacturing issues identified were continuous change, rapid responses, social responsibility and quality improvements. (Nagel 1992; Jin-Hai et al. 2003)

According to Nagel (1992), rapid product creation, development and modification are considered as important aspects in agile manufacturing, and they are made possible by:

1. The routine formation of inter-disciplinary project teams being able to concurrently develop product designs and manufacturing process specifications
2. Extending the concept of design to the entire projected life cycle of a product
3. Accurately simulating product performance characteristics and modelling the entire manufacturing process
4. Flexible, modular, reconfigurable and affordable production processes and equipment
5. Obtaining and sharing relevant information quickly with project members distributed throughout a firm or firms, and linking that information directly to production machinery
6. Modular product design enabling reconfigurability and upgradability leading to extremely long product lifetimes

2.2 Definitions of agility

Agility can be investigated from various viewpoints, and existing literature offers a lot of different definitions. A list of 10 definitions is collected to table 1 to provide an overview.

***Table 1**: Definitions of agility.*

Reference	Definition
Kidd, 1995	An agile corporation is a fast moving, adaptable and robust business enterprise capable of rapid reconfiguration in response to market opportunities.
Gunasekaran, 1998	Agile manufacturing is the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services.
Naylor et al. 1999	Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market place.
Yusuf et al. 1999	Agility is the successful exploration of competitive bases (speed, flexibility, innovation, proactivity, quality and profitability) through the integration of reconfigurable resources and best practises in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment.
Bullinger, 1999	Agility means mobility in an organisation's behaviour towards the environment and can therefore be understood as an extensive answer to continually changing markets.
Christopher, 2000	Agility is the ability of an organization to respond rapidly to changes in demand, both in terms of volume and variety.
Christopher, 2005	Agile businesses have a number of distinguishing features: they are market sensitive; they are information based and they share that information across their supply network; and finally, their processes connect easily with those of their supply chain partners.
Swafford et al. 2006	Agility is derived from three building blocks of relevancy, accommodation, and flexibility. Relevancy is the ability to maintain focus on the changing needs of customers. Accommodation is the ability to respond to unique customer requests. Flexibility is the ability to adapt to unexpected circumstances.
Zhang & Sharifi, 2007	Agility is a manufacturing strategy that aims to provide manufacturing enterprises with competitive capabilities to prosper from dynamic and continuous changes in the business environment, reactively or proactively.
McCann et al. 2009	Agility is the capacity for moving quickly, flexibly and decisively in anticipating, initiating and taking advantage of opportunities and avoiding any negative consequences of change.

There is not one unique definition of agility as table 1 illustrates but similar aspects among various definitions can be identified. Responding quickly to changes in volatile environment, and seeing changes as opportunities rather than threats, are characteristics of agility in common level. Some authors clearly stated that agility is a capability of a company, whereas other sources considered it as a strategy or a paradigm. However, change in general is the main driving force behind agility.

A concept of flexibility is closely connected to agility. As table 1 indicates, flexibility in some form is mentioned in three agility definitions. Christopher (2000) stated that flexibility is a key characteristic of an agile organization. Volberda & Rutges (1999) defined organization's flexibility as *"the degree to which an organization has a variety of actual and potential managerial capabilities, and the speed at which they can be activated, to increase the control capacity of management and improve the controllability of the organization"*. It has to be noted that flexibility can be defined in various ways depending on the context and approach. When flexibility is approached from a manufacturing system's viewpoint, Wiendahl et al. (2007) introduced the following definition: *"flexibility describes the ability of a system to change its behaviour without changing its configuration"*. Furthermore, Wiendahl et al. (2007) defined five classes of changeability, each of them referring to different product- and production level, as shown in figure 1.

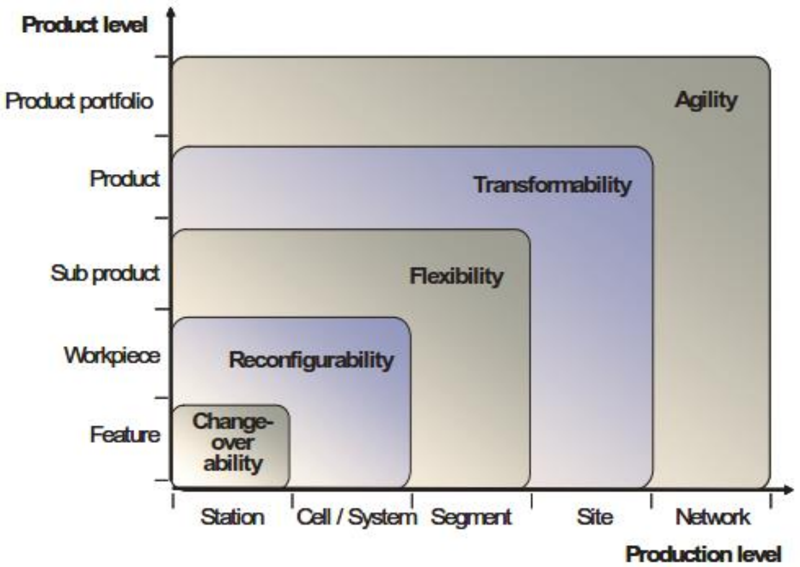

***Figure 1**: Five classes of changeability (Wiendahl et al. 2007).*

In the above changeability classification, flexibility means *"the tactical ability of an entire production and logistics area to switch with reasonably little time and effort to new – although similar – families of components by changing manufacturing processes, material flows and logistical functions"*. Agility, in turn, is defined as *"the strategic ability of an entire company to open up new markets, to develop the requisite products and services, and to build up necessary manufacturing capacity"*. However, Wiendahl et al. (2007) pointed out that any changeability class at a higher level subsumes the types below it. Therefore, considering that statement, agility includes flexibility in some context.

2.3 Enablers of agility

In this chapter, aim is to investigate enablers of agility meaning different tools, practices and characteristics that are connected to agility. First, a focus is on reviewing literature related to agile manufacturing concept. A framework created by a famous agility researcher Gunasekaran presents various practices and tools that are categorized under four broader topics. Second, a relatively narrow model introduces four core concepts of agile manufacturing. Third, a short introduction on flexible and reconfigurable manufacturing systems is made. Finally, the viewpoint is shifted to supply chain agility, as characteristics and elements of an agile supply chain are discussed.

2.3.1 Framework of agile manufacturing system

Gunasekaran (1999) created a framework, which presents different enablers of agile manufacturing system divided under four major categories as presented in figure 2. Gunasekaran identified some of the enablers by himself, but added various insights from other literature sources. Therefore, the content is comprised of different sources. Next, each of the four categories is opened.

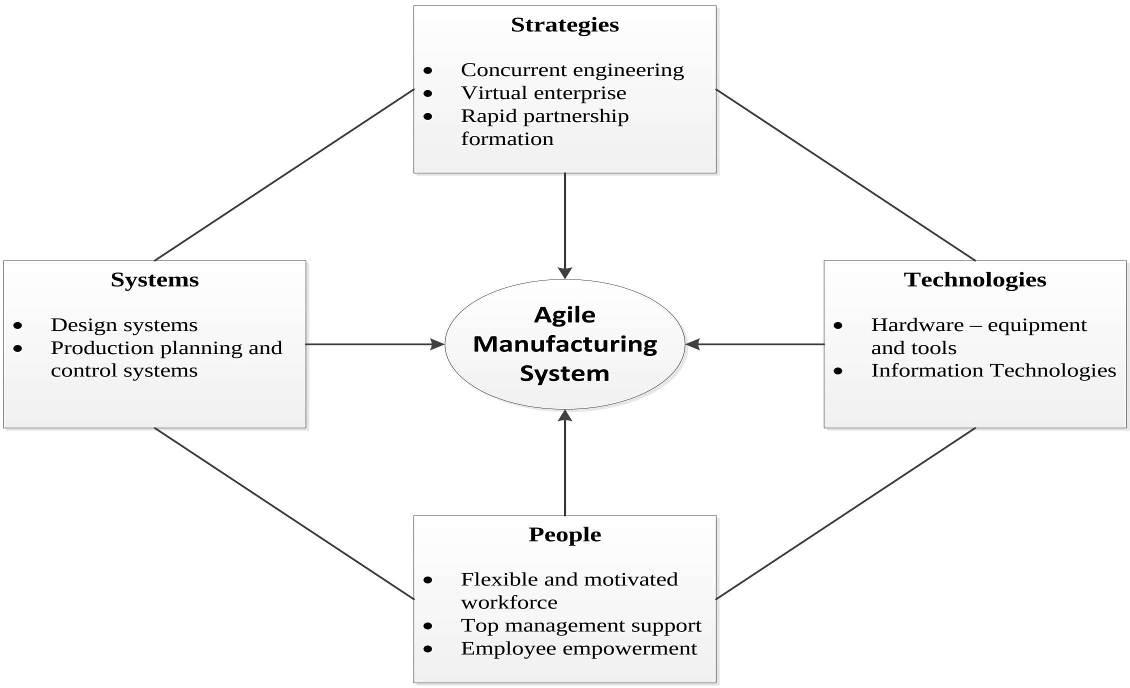

***Figure 2**: Framework of agile manufacturing system, modified from (Gunasekaran 1999).*

Strategies

According to Gunasekaran (1999), agile manufacturing itself is a strategy. However, several sub-strategies can be connected to it. Technologies and systems alone are unable to achieve agility without suitable strategies. Gunasekaran mentioned Concurrent Engineering (CE) as a strategy, which helps managing change in a manufacturing environment. CE is a systematic approach of concurrently designing both the product and the downstream processes for production and support. (Gunasekaran 1999)

In virtual enterprise the core competencies of carefully chosen real organizations are integrated as temporary alliances are formed. This leads to quick and cost-effective manufacturing by taking advantage of resources and diverse skills of different organizations. (Gunasekaran 1999) The organizations forming the virtual enterprise are cooperating at the corporate and operational levels as if they were one enterprise (Elmoselhy 2013). Virtual enterprise is a useful strategy, since a single organization may not be capable of responding quickly enough to changing market requirements.

Rapid partnership formation is a critical element, which has to be based on core competencies and temporary alliances. It includes prequalifying partners, evaluating the product design capabilities of potential partners and selecting the optimal set of partners. Cost, responsiveness, quality of goods and services, location of the company and IT skills should form the criteria for selecting partners. (Gunasekaran 1999)

Systems

In this category, Gunasekaran mainly approaches the subject from product design's point of view. Rapid product design systems allow switching over to new products as quickly as possible, which is important in agile manufacturing (Gunasekaran 1999). However, product design systems are beyond the scope of the thesis. Hence, they are not discussed here any further.

According to Gunasekaran (1999), other important systems in agile manufacturing include production planning and control systems. Here, he does not introduce these systems in more detail. Tu (1997) stated that traditional production control and management systems, methods and theories are unable to satisfy agile companies' needs for production planning and control. Therefore, the following aspects should be considered: (1) modelling of evolutionary and concurrent product development and production under a continuous customer's influence; (2) real-time monitoring and control of the production progress in a virtual company; (3) a flexible or dynamic company control structure to cope with uncertainties in the market; (4) adaptive production scheduling structure and algorithms to cope with uncertainties of production state and control system in a virtual company; and (6) the reference architecture for a virtual company. (Tu 1997) Production planning and control systems are introduced later in chapter 2.5.

Technologies

Rapid hardware changeover by robots, flexible part feeder, modular grippers, and modular assembly hardware are examples of agile-enabled technologies. They are useful, when a rapid changeover from the assembly of one product to the assembly of a different one is needed. (Gunasekaran 1999)

Gunasekaran (1999) stated that Information Technology (IT) has a fundamental role in integrating physically distributed manufacturing firms in today's global manufacturing environment. Avoiding human related errors in information exchange is one key issue which can be addressed by increasing the use of IT. Virtual enterprises, in turn, require technologies such as Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) to eliminate non-value adding activities in the supply chain. (Gunasekaran 1999)

People

A common problem identified in agile environment is how to motivate and manage the workforce to support agility. If information flow is disturbed by human issues, agility is lost. That is why human points of failure need to be eliminated by suitable technologies and systems. People need to be willing to accept agile practices and enabling technologies. Otherwise often deeply ingrained old and traditional practices cannot be overcome. Radical changes in the line of re-engineering business processes demand a great support from top management in terms of providing technical and financial support. (Gunasekaran 1999) Employee empowerment enables quick decisions and actions taken by employees, thus having a significant impact on the rate of order fulfilment (Yusuf et al. 1999).

An agile workforce should be multi-skilled and flexible, thus having a capability of shifting job functions and carry out other tasks rapidly, when a need occurs. Therefore, agile companies must be committed to continuous workforce training and education. Continuous learning, self-organising -and reconfigurable teams are attributes of an agile workforce. (Jin-Hai et al. 2003; Sharp et al. 1999) Same kind of characteristics for agile workforce were identified already earlier by Kidd (1995), who mentioned that highly skilled, flexible, motivated and knowledgeable people are needed in an agile company.

2.3.2 Four core concepts of agile manufacturing

Yusuf et al. (1999) introduced four core concepts, from which their model for agile manufacturing is built. This model, shown in figure 3, also includes the concept of virtual enterprise, which was listed as a strategy in Gunasekaran's framework. Since virtual enterprise was already introduced earlier, it is only necessary to focus on the other three concepts that are introduced next.

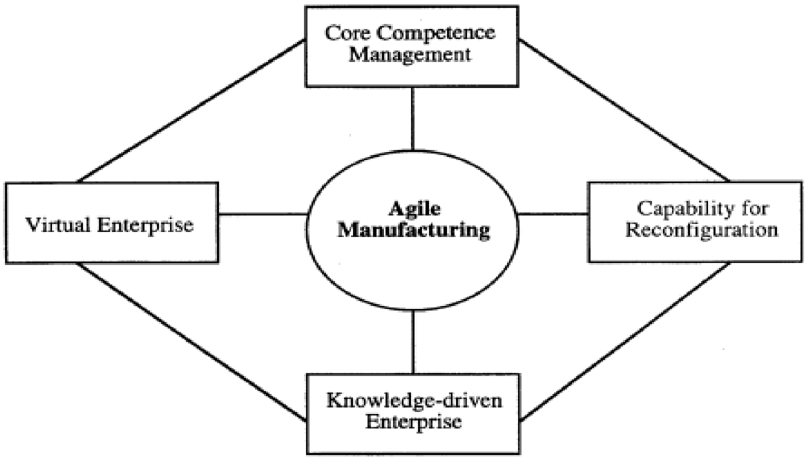

Figure 3*: The core concepts of agile manufacturing (Yusuf et al. 1999).*

Core competencies can be divided into firm competencies and individual competencies. Abilities and assets of the firm are considered as firm competencies. Skills, knowledge, expertise and attitude of the workforce are recognized as individual competencies. They can be upgraded and re-focused to take advantage of current and potential trends in customer requirements by investing in training and education. Core competencies are strategically important while they need to bring long-term benefits to the corporation. (Yusuf et al. 1999) Identification of a core competence can be done by testing if three conditions are fulfilled: (1) It should enrich the end product's customer value; (2) it should be difficult to copy for competitors; (3) it should enable access to wide spectrum of markets (Prahalad & Hamel 1990).

In knowledge-driven enterprise the development of motivated and well-trained workforce with the needed skills, expertise and knowledge, is an essential factor of strategy. The ability of converting the collective knowledge and skills of people into products is an important factor to enable organisation's success. The exploitation of a knowledge-rich work force is needed for controlling the new product introduction process from the conceptualisation and design phases through manufacturing to delivery and product support. Besides the capabilities of work force, knowledge can be improved by utilizing company reports, case histories and databases. (Yusuf et al. 1999)

The capability for reconfiguration means that an agile enterprise can rapidly shift its focus and re-align its business for taking advantage of new opening opportunities (Yusuf et al. 1999). According to Kidd (1995), reconfiguration may be required within facilities, people, organization, technology and corporate structures in order to respond to often unexpected and short-lived market opportunities. As stated by Yusuf et al. (1999), developing a strategic architecture featuring a corporate wide map of core skills is one key to reconfiguration capability. This helps organisations to take advantage of speed, by entering to the market with new products before competitors. On the other hand, improving operational reconfigurability at the plant level is needed, and this requires investments in technologies supporting operational flexibility. (Yusuf et al. 1999)

2.3.3 Flexible and reconfigurable manufacturing systems

As was already mentioned earlier, according to Wiendahl et al. (2007), agility includes four other types of changeability, which are changeover ability, reconfigurability, flexibility and transformability. Therefore, flexible and reconfigurable manufacturing systems can also be considered as enablers of agility from manufacturing point of view. Koren et al. (2000) stated that reconfigurable manufacturing systems and agility share a focus on the objective of manufacturing responsiveness.

Flexible manufacturing systems, which were developed to accommodate fluctuations and turbulences in production, are able to produce a variety of products on the same system with changeable mix and volume. They consist of general-purpose Computer Numerically Controlled (CNC) machines and other programmable automation. (Wiendahl et al. 2007; Koren et al. 1999) Flexible manufacturing systems are designed for production requirements that are quite loosely defined and expected to vary over time. That is why excess capability is often included in flexible manufacturing systems. (Landers et al. 2006)

Reconfigurable manufacturing system (RMS) is customized to its initial production requirements and may be converted, in both hardware and software, such that customization to new specific range of production requirements can be done (Landers et al. 2006). According to Koren (2006), "*RMS is a system designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family*". Changeable components may be machines and conveyors in entire systems, new sensors, new controller algorithms or mechanisms for individual machines (Koren et al. 2000).

2.3.4 Agile supply chain

According to Prater et al. (2001), supply chain is usually the part of a company, which is heavily affected by changes in today's international business environment. In many cases, supply chain agility may be considered as a limiting factor of company's overall agility. Swafford et al. (2006) defined supply chain agility as *"supply chain's capability to adapt or respond in a speedy manner to a changing marketplace environment".* Through agile supply chain processes, firms have better capability of synchronizing supply with demand, and shorter cycle times can be achieved. Therefore, supply chain agility has an impact on organisation's ability to produce and deliver innovative products to customers. (Swafford et al. 2006)

According to Christopher (2000), an agile supply chain consists of following elements: market sensitive, virtual supply chain, process integration and network. *Market sensitive* refers to supply chain's capability to read and respond to real demand. This means being demand-driven rather than forecast-driven. Most organizations lack having enough data of actual customer requirements, therefore they are forecast-driven, which often causes unnecessary inventories. The increased utilization of IT to capture data on demand enhances organization's ability to respond directly to market needs. *Virtual supply chain* is information-based which basically means that information is shared between buyers and suppliers by using IT. For effectively sharing information between supply chain partners, *process integration* is needed. It consists of, for instance, integrating product development activities and common systems with suppliers and buyers. Transparency of information comes along with process integration. The fourth element of an agile supply chain is *network* which links different partners together in order to gain sustainable advantage in today's challenging global markets. When strengths and competencies of network partners are combined, greater responsiveness to market needs can be achieved. (Christopher 2000)

Besides the four elements discussed above, Christopher (2000) emphasized that the quality of supplier relationships is an issue, which is also closely connected to supply chain agility. For instance, the lead time of the part supply from suppliers often affects manufacturer's ability to rapidly respond to changing customer requirements. On the other hand, involving suppliers to the innovation processes can enable faster new product introduction time, thus increasing agility. The supplier base should be rationalized, since creating close relationships with multiple suppliers is difficult through process integration. The key suppliers should be able to synchronize their production and deliveries with the requirements coming from their downstream partners. The high amount of shared information is one prerequisite for the formation of an agile supplier base. It is obvious that any mistrust between the partners should not exist, since information needs to flow freely to both directions in the supply chain. Data on real demand from downstream has to be captured and shared rapidly with upstream suppliers through an effective use of IT-systems. (Christopher 2000)

Meredith & Francis (2000) highlighted that supply chain agility can be enhanced by building partnerships, sharing goals and eliminating barriers between the firm and suppliers. These actions can result in benefits like more reliable supplies, shorter lead times, higher quality and more accurate exchange of information.

2.4 Lean manufacturing elements supporting agility

This chapter reviews Lean elements that can be utilized in supporting agility. The first section focuses purely on giving an introduction to Lean manufacturing by explaining some key characteristics and principles linked to it. Then in the second section, waste reduction including eight types of non-value adding activities is discussed as a supporting Lean element for agility. The third section takes a look at continuous improvement, which is traditionally closely connected to Lean thinking, but can be also considered as a supporting element for agility.

2.4.1 Introduction to Lean manufacturing

Lean manufacturing is considered as a both famous manufacturing paradigm and management philosophy, which has mainly evolved from Japanese car manufacturer Toyota's well known production system. The basic idea behind Toyota Production System (TPS) is to add value for the end customer by eliminating wasteful non-value-adding activities from production processes. As introduced in (Toyota-global 2015), TPS has two main concepts: Just-In-Time (JIT) and jidoka. JIT aims on producing what is needed at the right time in the right amount. Jidoka can be translated as "automation with a human touch", meaning that quality is built in production process so that equipment stops as a quality problem occurs and human can correct the problem.

According to Womack & Jones (1996), Lean provides a way to do more with less human effort, less equipment, less time and less space, while coming closer to providing customers exactly what they want. Liker (2004) introduced altogether 14 lean principles that he identified while studying for 20 years Toyota's way to do business. The principles were divided into four categories all starting with "P", thus forming the 4P model, shown in figure 4.

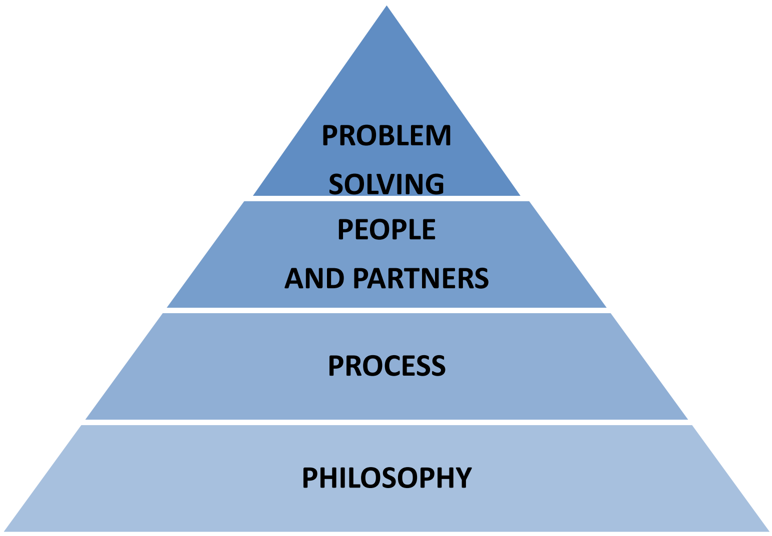

Figure 4*: The 4P model of Toyota, modified from Liker (2004).*

The pyramidal shape of the model indicates that creating a philosophy is the starting point and other categories are built on top of it. It is not necessary to go into details with all the 14 principles. Therefore only the main points linked to these principles identified by Liker (2004) are listed next.

Philosophy

- Management decisions need to be based on a long-term philosophy
- Generating value for the customer, society, and the economy

Process

- Creating continuous process flow to bring problems visible

- Avoiding overproduction by providing the customers and next phases in the production process with right amount of needed items at the right time
- Levelling out the workload
- Building a culture of stopping to fix quality problems
- Standardizing tasks to form a foundation for continuous improvement and employee empowerment
- Using visual control so that problems are not hidden
- Using reliable and thoroughly tested technology, which serves the processes and people

People and partners

- Teaching and growing leaders, who understand and adopt the philosophy, and can teach it to others
- Creating a stable and strong culture, in which the common values and beliefs can be widely shared
- Respecting the partners and suppliers by giving them challenges and helping them to continuously improve

Problem solving

- Solving problems and improving processes by going to the source of problems to thoroughly understand the situation
- Making decisions carefully by considering all options, and then implementing decisions rapidly
- Creating a learning organization through continuous improvement

2.4.2 Waste reduction

Naylor et al. (1999) noted that agile manufacturing also aims to reduce as much waste as possible, but the elimination of all waste is not emphasized as a prerequisite. According to Alves et al. (2012), an agile company must be lean by means of being focused on satisfying customers without waste, which often delays its activities and compromise the needed agility. Liker (2004) introduced eight types of non-value-adding wastes, adding one to the original list defined by Toyota:

1. **Overproduction**: producing items for which no orders exist.
2. **Waiting**: standing around while waiting for the next processing step, part, tool or having no work due to other problems e.g. capacity bottlenecks.
3. **Unnecessary transport or conveyance**: moving materials and parts to and from storage, or carrying work in process long distances.
4. **Over processing or incorrect processing**: producing higher quality than is needed, or taking unnecessary steps to process the parts.
5. **Excess inventory**: excess works in process, raw material, or finished goods hide problems and cause longer lead times.

6. **Unnecessary movement**: any wasted motion worker has to perform during the work.
7. **Defects**: producing or repairing defective parts.
8. **Unused employee creativity**: losing time, ideas, improvements, or skills by not engaging or listening to employees.

Liker (2004) highlighted that overproduction is the fundamental waste because it easily causes most of the other identified types of wastes. Producing more than is actually needed leads to a build-up of an unnecessary inventory. This again can reduce the motivation to continuously improve operations, as inventories tend to hide underlying problems. For example, machine shutdowns do not immediately disturb final assembly if buffers are held between processes. (Liker 2004)

2.4.3 Continuous improvement

Sharp et al. (1999) mentioned that continuous improvement is one enabler of agile manufacturing. Their definition of continuous improvement is "*reiterative process of planning, changing, evaluating and improving elements within the organisational structure*". Developing a culture of continuous improvement, in which employees are actively engaged in making initiatives and implementing improvements to the company, serves as a foundation for agile manufacturing (Leanproduction 2015).

Liker (2004) pointed out that continuous improvement is translated from Japanese term kaizen, meaning a total philosophy thriving for perfection through the process of making incremental improvements. Continuous improvement requires processes to be stable and standardized in order to make waste and inefficiencies visible. That again enhances learning from improvements. The core of continuous improvement and learning is an attitude of self-reflection, even self-criticism, and having a great desire to improve things. (Liker 2004)

Imai (1986) used the term kaizen as an umbrella covering many uniquely Japanese practices which later on came more famous as Lean principles. Kaizen emphasizes problem-awareness and provides ways to identify problems. Recognizing the need is the starting point for any improvement. Kaizen also serves as a problem-solving process, which requires the use of various problem-solving tools. Imai made clear difference between innovation and kaizen by stating that innovation as technology-oriented improvement calls for large investment, whereas kaizen demands greater deal of continuous effort and commitment from people. However, innovation should be made after kaizen has been exhausted, and kaizen again should follow straight after innovation is initiated. The role of standardization is of great importance, since standards need to exist so that they can be superseded by better standards. (Imai 1986)

2.5 Manufacturing IT-systems supporting agility

Fast and easy interchange of information in dynamic manufacturing environment requires IT-systems that support and enable quick responds to changes. Goldman et al. (1995) noted that IT-systems are considered as a critical and fundamental part of any change towards agility. Mondragon et al. (2004) emphasized the importance of IT-systems in supporting manufacturing, and stated that for instance real-time monitoring of manufacturing operations enhances manufacturing agility. According to Kletti (2007), faster flow of information between every level in a manufacturing company enable problems and unplanned events to be detected faster. This helps achieving agility as rapid reactions are made possible.

Focus on this chapter is on Manufacturing Operations Management (MOM) systems. ISA-95 standard classifies five different levels, in which information is managed and exchanged between business level operations and shop floor operations (Apriso 2012). These levels with corresponding activities are illustrated in figure 5. MOM systems are targeted in level 3. According to ANSI/ISA-95.00.03, *"MOM includes the activities of managing information about the schedules, use, capability, definition, history, and status of all of the resources (personnel, equipment and material) within and associated with the manufacturing facility"*.

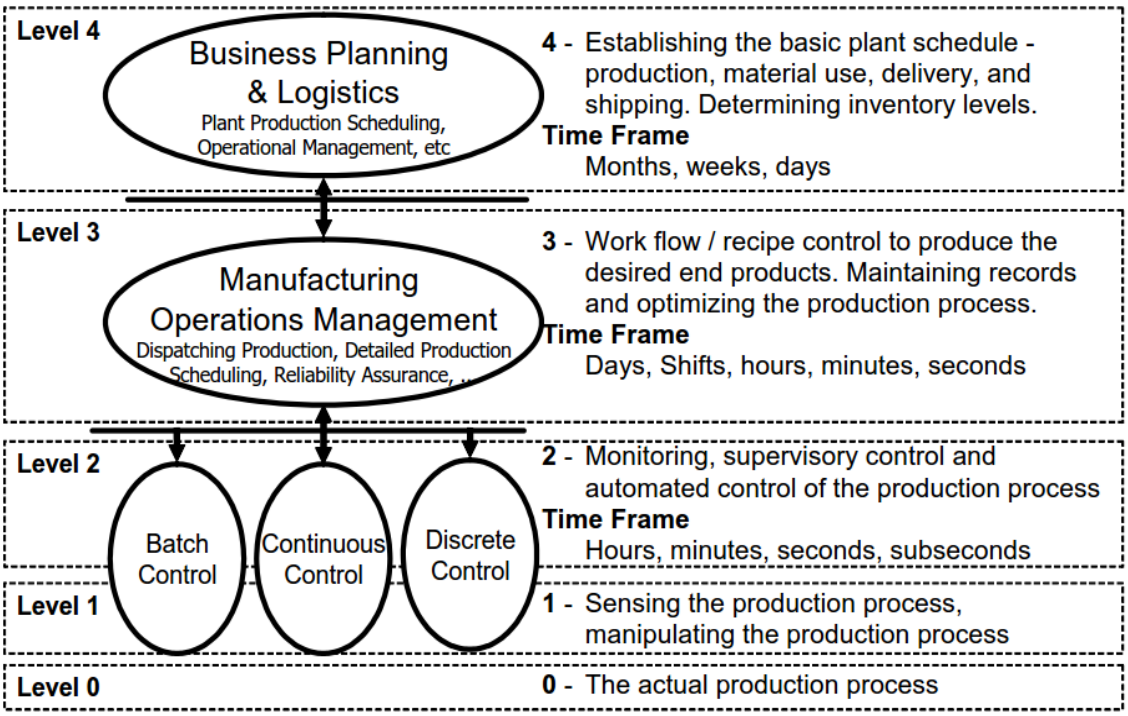

Figure 5*: ISA-95 hierarchy model (ANSI/ISA-95.00.03).*

Manufacturing Execution Systems (MES) and Advanced Planning and Scheduling (APS) systems, introduced in chapter 2.5.1 and 2.5.2, are included in MOM systems in level 3. Enterprise Resource Planning (ERP) systems belong to level 4, which according to ANSI/ISA-95.00.03, includes functions involved in the business-related activities needed to manage a manufacturing organization. According to Shehab et al. (2004), ERP is a business management system including integrated sets of comprehensive software, which can be used to manage and integrate business functions within an organization. Kletti (2007) noted that ERP can be used for rough production planning but it is not suitable for detailed planning or production control. MES is needed to manage and control the production operations and transfer information between production resources and ERP (ANSI/ISA-95.00.03). APS in general takes care of detailed planning and scheduling of the production before the operations takes place (Järvenpää et al. 2015). Figure 6 presents MOM functions that belong to level 3. As can be noted from figure 6, both MES and APS functionalities are included in MOM.

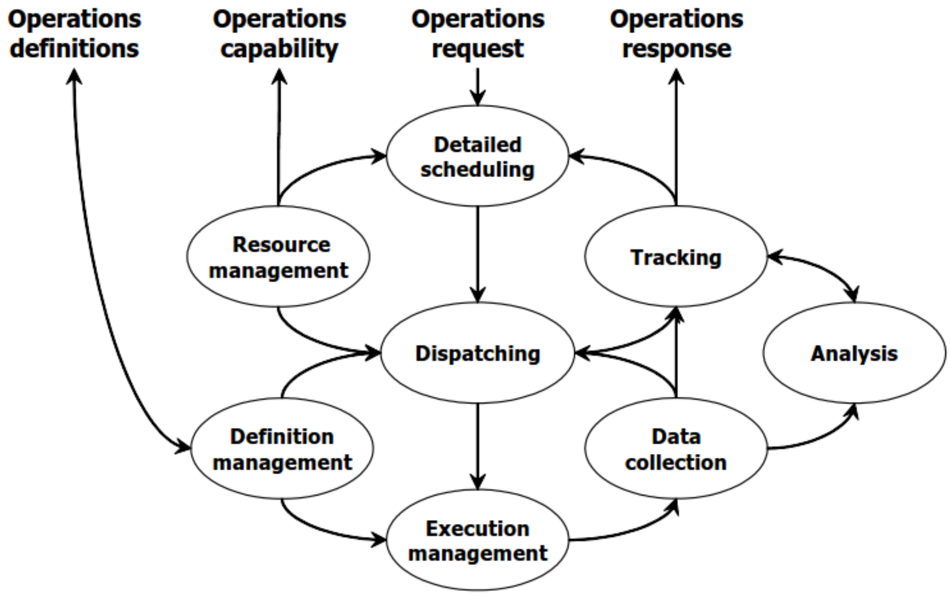

Figure 6*: Functions of manufacturing operations management (ANSI/ISA-95.00.03).*

MES and APS systems are reviewed next in more detail. It must be noted at this point that the existing literature does not make very clear distinction between these systems regarding their definitions and functionalities. Therefore, some issues discussed within the MES-section are dealing with issues related to APS and vice versa.

2.5.1 Manufacturing Execution Systems

MES include a collection of functions focusing on executing production activities. MES are used for delivering information that enables the optimization of production activities straight from order launch to finished products. MES respond to and report about plant activities when they occur by using accurate real-time data. (MESA 1997) According to Kletti (2007), MES have been developed from classic disciplines such as production data acquisition, quality assurance, staff work time logging and finite scheduling. MES serves the relevant applications with real-time status information about machines, orders, tools, materials and personnel. As MES supply information in the production environment, they must meet the following requirements: the right information at the right place, fast and ergonomically presented. (Kletti 2007) Fraser (2011) noted that an MES is a factory floor execution system which provides required visibility and event notifications to ensure that manufacturing can meet enterprise's information demands. MES provide the ERP systems with needed real-time production information, thus reducing the dependence on manual data entry. (Fraser 2011)

Manufacturing Execution System Association (MESA) defined 11 function groups of MES. Within these groups, functions related to APS systems also exist, namely operations/detail scheduling which is mentioned as second group in the list. These 11 groups are listed below (MESA 1997):

1. **Resource allocation and status**: provides detailed history data and real time status information of resources such as machines, tools, materials and operators. It ensures that needed resources are reserved for operations.
2. **Operations/detail scheduling**: provides sequencing and scheduling of activities to achieve an optimized performance for plant.
3. **Dispatching production units**: gives commands to send work orders, lots and materials to certain parts of the factory to start a process or a work phase.
4. **Document control**: manages, gathers and distributes information on orders, designs, products or processes.
5. **Data collection/acquisition**: monitors, gathers and organize data about the performance of operations, processes, materials and operators.
6. **Labour management**: tracks and directs the use of production workers during their work based on working patterns, qualifications or special business needs.
7. **Quality management**: tracks, records and analyse the characteristics of products and processes against the designed quality requirements.
8. **Process management**: monitors and directs the work flow in production based on the planned and actual situation.
9. **Maintenance management**: ensures the availability of machines, equipment and tools by tracking their conditions and scheduling proactive maintenance.
10. **Product tracking and genealogy**: provides the visibility to the location and status of the work, and allows traceability.
11. **Performance analysis**: provides real time reports of measured performance results and compares them to past history results and planned performance requirements.

Meyer et al. (2009) introduced benefits that companies can achieve by implementing an MES. Integrated data transparency is a benefit which means that an MES enables integrated data recording and performance monitoring in real time. Reduced time usage as a broader category was mentioned as a remarkable benefit which is comprised of several factors such as reduced planning times, reduced cycle times and reduced waiting times in production. Reduced administration expenses refer to the fact that the amount of documents used can be reduced significantly by implementing an MES. Having up-to-date information about the progress of orders results in more reliable delivery dates and improved customer service. The real-time control of influencing parameters in production helps recognizing deviations immediately. Therefore, an MES has a role of an early warning system. An important benefit related to employees is increased employee productivity. An MES can electronically provide the needed real-time information for production workers so that they can spend less time searching for information and focus on actual work. (Meyer et al. 2009)

Some other relevant benefits of MES are mentioned in Camstar's website. MES reduce human errors in production by means of providing real-time quality data checks and reducing the amount of paperwork needed on the factory floor. Having a complete control over the whole manufacturing process gives managers ways to make operational and strategic decisions based on facts. Furthermore, the real-time feedback provided by MES helps identifying and resolving issues for product and process improvement. (Camstar 2015)

2.5.2 Advanced Planning and Scheduling systems

APICS (2007) gave the following definition for an Advanced Planning and Scheduling (APS) system: *"An APS system is any computer program that uses advanced mathematical algorithms or logic to perform optimization or simulation on finite capacity scheduling, sourcing, capital planning, resource planning, forecasting, demand management, and others. These techniques simultaneously consider a range of constraints and business rules to provide real-time planning and scheduling, decision support, available-to-promise, and capable-to-promise capabilities. APS often generates and evaluates multiple scenarios".*

Stadler (2005) noted that APS systems were developed because ERP systems lack capabilities related to planning. Setia et al. (2008) agreed by stating that APS systems are a natural extension to the ERP systems, but often combinations of these systems are used in guiding supply chain planning and collaboration. APS systems are especially needed in complex environments characterised with high amount of product categories, uncertain supply conditions and changing demand. (Setia et al. 2008)

Kletti (2007) noted that the functions of APS systems can be either closer to ERP or MES, depending on the production type. Setia et al. (2008) made a short comparison of characteristics of APS and ERP systems, presented in table 2.

***Table 2**: Comparison of characteristics of APS and ERP systems, modified from (Setia et al. 2008).*

APS	**ERP**
• Real time analysis for planning, scheduling and optimization decisions • Material and capacity constraints evaluated together to optimize the decisions	• Real-time analysis and simulation to aid dynamic decision making not supported by the technology • No consideration for interdependency of material and capacity availability
• Multi-plant planning supported	• Multi-planned planning not supported at the same time
• Ability to calculate lead-times dynamically	• Lead times assigned statically and manually
• Optimized production schedules to increase throughput	• Lack of optimization capability for production schedules

In terms of structure of APS systems, Meyr et al. (2002) introduced the Supply Chain Planning (SCP) matrix which includes planning tasks that are considered as modules of APS systems. As figure 7 illustrates, SCP-matrix has two dimensions: planning horizon in y-axis and supply chain process in x-axis.

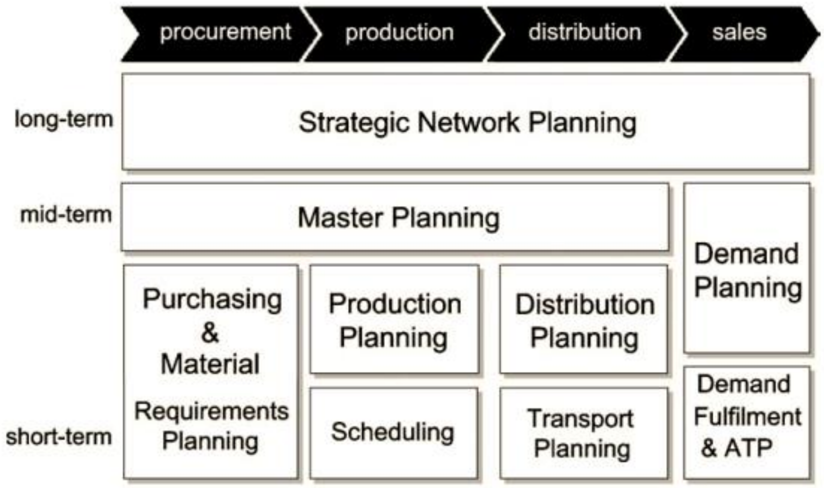

***Figure 7**: Modules of APS systems presented in SCP-matrix (Meyr et al. 2002).*

Strategic network planning includes tasks like deciding the location of plants and designing the physical structure of distribution. *Master planning* is responsible of balancing demand forecasts with available capacities on a mid-term planning level. *Purchasing & material requirements planning* performs the calculations of procurement quantities, and the module is also used for fixing the planned production amounts of bottleneck operations. *Production planning* performs lot-sizing within an individual production department or plant site, and *scheduling* refers to detailed scheduling of machines. *Distribution planning* deals with the flow of goods between sites, taking care of transports of products straight to customers or to warehouses. *Transport planning* is used for e.g. sequencing customer locations on a trip of each vehicle. *Demand planning* provides sales forecast for short, medium and long terms by utilising both available and planned customer orders. *Demand fulfilment & ATP* (available-to-promise) module serves as an interface to the customers, including tasks such due date setting and tracking customer orders from order entry to delivery. (Meyr et al. 2002; Stadtler 2005)

According to Setia et al. (2008), APS systems are useful for evaluating impacts of possible changes in customer demands or resource availability. For instance, at the operational level, APS systems are able to determine the following aspects: (1) How fast changing customer demand is possible to accommodate in manufacturing schedules; (2) How soon operating decisions can be refined following technical improvement; (3) How soon operators and resources can be redeployed to match changes in production schedule and (4) How fast suppliers can be reconfigured to maintain the continuous material supply during changes in supply conditions. (Setia et al. 2008) APS systems are capable of planning material requirements and capacity simultaneously. They can also simulate different scenarios fast. These capabilities make them well suitable to adapt to various changes in demand, material availability or resource capacity. (EyeOn 2015) The utilization of APS systems enhances opportunities to re-schedule jobs, reassign resources and reconfigure processes. These characteristics, according to Setia et al. (2008), indicate that APS systems can result in greater agility.

3. RESEARCH METHODOLOGY

This section introduces the research methodology used in the thesis. Chapter 3.1 explains the structure of the company interviews, from which data for the research was collected. The group of interviewed companies as well as the topics discussed in the interviews are introduced in the same chapter. Chapter 3.2 first presents which questions from the interviews were selected for analysis and what was the reasoning behind the selection. Then methods used in analysing the material are presented.

3.1 Data collection

Qualitative data was collected by conducting one interview round among 25 Finnish manufacturing companies during the fall 2013 and spring 2014. The interviews were part of the LeanMES-project, and since they were made at the early phase of the project before this thesis started, the author did not participate in the actual data collection process. The main goal of the interviews was to investigate challenges and needs that companies have related to manufacturing operations management practices and tools.

The group of interviewed companies consists of sub-contracting companies and Original Equipment Manufacturers (OEM) that have their own end product. The companies operate mainly in machine building industry. Based on the amount of employees, companies were grouped to small and medium-sized (SME) companies (less than 250 employees) and large companies (more than 250 employees). (Järvenpää et al. 2015) Table 3 presents the grouping of interviewed companies. Names of the companies are not mentioned in this thesis, since the anonymity must be maintained.

Table 3*: Grouping of interviewed companies (Järvenpää et al. 2015).*

Company type	Company size	Amount of companies
OEM	SME (< 250 employees)	8
Sub-contracting	SME (< 250 employees)	9
OEM	Large (> 250 employees)	8

Each interview session consisted of interview of three types of personnel: 1) production manager, 2) production worker and 3) IT manager or main user of the production planning and execution system. Total of 80 standardized open questions were asked in interviews. All questions were asked from the production manager, whereas the other two type of interviewees answered only to questions that were relevant for them. The total amount of interviewed personnel was 95. (Järvenpää et al. 2015) The questions were grouped to four categories under different topics. Table 4 shows the categories and topics.

Table 4: *Question categories and topics, adapted from (Järvenpää et al. 2015).*

Production planning and control tools and practices	**Shop floor level production control**	**Key performance indicators (KPIs)**	**Lean practices and tools**
▪ IT-tools from production planning to shop floor level control ▪ Integration level of IT-systems used in production management and control ▪ Communication in the production network ▪ Maintenance and quality control ▪ Challenges in current production planning and control practices and tools ▪ Requirements for future's MES	▪ Demand forecasting and reacting to fluctuations ▪ Control of inventories ▪ Management of problems and change situations ▪ Flexibility of the production ▪ Development areas in the shop floor level production control	▪ Currently used KPIs in different work phases ▪ Collection of the KPI data ▪ Tools and methods used in analysing the KPI data ▪ Utilization of the KPI data	▪ Familiarity of Lean philosophy ▪ Currently used Lean practices and tools ▪ Material control and flow ▪ Standardization of processes and work instructions ▪ Involvement, respect and motivation of the workers ▪ Support of current IT-systems for Lean

3.2 Data analysis

The first section of this chapter explains the reasoning behind selecting certain questions from the interview material for analysis. The selected questions are then presented and shortly discussed. The second section introduces the cause-effect method, which was utilized in analysing interconnections between the identified challenges.

3.2.1 Selection of questions for analysis

In the first part of analysing the collected interview material, the focus was on finding challenges that are hindering agility in the interviewed companies. A challenge in this context means a problem, which needs to be solved in order to improve agility. For example, lack of proper IT-tools for production planning and scheduling is a challenge that hinders rapid reaction to changes and disturbances. Number of characteristics and enablers of agility collected from literature were utilized to identify the relevant question topics which should provide answers. For instance, effective information sharing in the supply chain was identified as an agility enabler in chapter 2.3.4. Therefore, the topic *"communication in the production network"* may include relevant questions which provide challenges. The following list presents the questions that were selected to be analysed:

- What tools, systems and methods are used in different phases of the production control?
- How is the daily scheduling of the shop floor’s machines or assembly performed?
- How well different IT-systems used for production management and control are integrated? How much manual work is required in transferring information between these systems?
- How much real-time information is shared in the production network regarding inventory levels, capacities or status of the orders?
- What challenges there are related to information exchange in the production network?
- What challenges there are related to delivery reliability?
- How quality is monitored and how quality issues are reported?
- How is the work-in-process (WIP) controlled?
- How inventories are controlled?
- What kind of sudden change situations occur in production?
- What methods and tools are used for collecting the KPI data?
- How the metrics data is utilized in production controlling or other processes?
- What are the current challenges in production planning and control practices and tools?
- What functionalities and features would be required from future’s MES?
- Should digitalization be increased on the factory floor?
- Is company familiar with Lean philosophy? What Lean practices and tools are in use?
- How workers are involved in development tasks, decision making and problem solving?
- How workers concern job rotation? Is job rotation practised in company?
- How agilely workers can be moved from one work phase or machine to another one? Is their knowledge a limiting factor?

As the list above indicates, majority of the questions deal with issues related to control and management of manufacturing operations information. Although the last questions are directed to “softer issues” such as worker’s skills and their inclusion, the main focus is on investigating agility from the viewpoint of information management related to production.

The next step was to go through answers of the interviewed personnel for selected questions. Some challenges were clearly brought forward by the interviewees, whereas others were identified by researchers, who made the interviews and later presented the results in publication, by Järvenpää et al. (2014). Besides, the author identified some additional challenges. The collected challenges are introduced later in chapter 4.1.

3.2.2 Cause-effect analysis

After all the challenges were identified, interconnections between them were analysed. This was done by drawing cause-effect relationships between the challenges. A challenge, which is a cause, has an effect on one or more other challenges. Simultaneously, the same challenge can be an effect of one or more other challenges. Figure 8 presents a simplified case, where one challenge causes two other challenges.

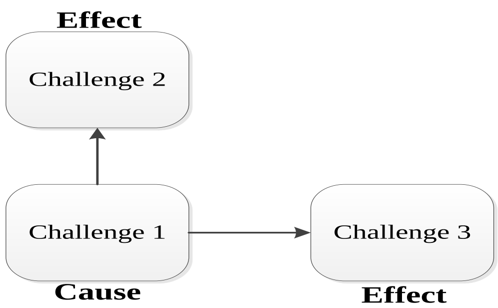

Figure 8: Example of cause-effect relationships.

The challenges that have effects on many other challenges are considered as possible root causes. One purpose of this analysis was to identify the root causes among the collected challenges. The analysis was done with an iterative approach. The majority of the cause-effect relationships were defined in a workshop, which was arranged among TUT's researchers working in LeanMES-project. Challenges written to post-it notes were categorized to white board, and relationships between them were drawn with marker pens. Figure 9 illustrates the preliminary result of the workshop.

***Figure 9**: Preliminary result of the workshop.*

In the workshop, the knowledge of the whole research group was utilized in analysing the relationships. At the end of the workshop, the white board was photographed, and later on results were visualized to relationships map drawn by author. The relationships map is presented and discussed in chapter 4.2.

4. CHALLENGES AND ENABLERS OF AGILITY IN FINNISH MANUFACTURING COMPANIES

Results of the thesis are presented in this section. Firstly, challenges that are hindering agility in the interviewed companies are presented in chapter 4.1. Secondly, analysed interconnections between challenges are visualized in relationships map, which is introduced and discussed in chapter 4.2. Thirdly, with help of the relationships map, critical root causes among collected challenges are analysed and discussed in chapter 4.3. Finally, in chapter 4.4, the focus shifts on turning challenges into actions that improve agility. The proposed actions are presented in action map, which illustrates the priority and costs of different actions. Furthermore, benefits achieved by implementing the proposed actions are listed in the same chapter.

4.1 Challenges hindering agility

This chapter consists of five categories, where different kind of challenges related to agility are presented. As was noted earlier, a challenge in this thesis means a problem, which needs to be solved in order to improve the agility of a company. First category includes challenges concerning currently used production planning and control practices and tools. Second category focuses on information management by introducing challenges dealing with issues such as communication, Key Performance Indicators (KPIs) and usage of IT-systems. Challenges in data collection and quality issues are opened up in third category. Fourth category then includes challenges connected to Lean practices and continuous improvement. Finally, in fifth category the focus shifts to challenges hindering production worker's performance on the shop floor. Even though challenges are group into these categories, majority of them somehow deals with information management. Therefore, some challenges could be relevant to mention in different category. However, this classification of categories makes the chapter easier to follow.

4.1.1 Production planning and control practices and tools

A major challenge regarding production planning and control is the lack of proper IT-tools. Utilization of both MES and APS-systems, according to literature, supports rapid reactions to changes. Only a couple of the interviewed companies use MES and none of the companies has an APS-system. Companies lack knowledge about these tools or they do not have enough resources to start implementing them. Therefore, utilization of ERP and various Excel spreadsheets is typical when it comes to production planning and scheduling. Besides, paper and pen are in use. Since many companies have identified the need to increase the planning accuracy of detailed scheduling, proper scheduling systems with APS functionality would be more suitable than currently used ERP-systems, which have limited planning accuracies. Lack of integration of ERP and various Excel-sheets is problematic, and it causes time-consuming manual updating of information, when changes need to be made. In case of re-scheduling of orders, ERP is not the fastest and easiest tool to perform it, as all the phases of the order must be re-scheduled separately. Due to various disturbances such as quality defects and unavailable components, re-scheduling is a typical task, which needs to be done relatively often in most of the companies. Therefore, the need for systems with APS functionality is obvious because re-scheduling with currently used tools is a slow and arduous task.

Due to lack of MES functionality, most of the companies control the production on the shop floor with paper work orders. With MES, companies could show the job queue on computer displays, thus increasing visibility and eliminating problems regarding searching for missing paper work orders. Change situations are typically handled on the shop floor, and information related to them may not be recorded to any information system. Instead, information stays on paper documents, which again leads to a problem, that needed up-to-date information for decision making is not available. These issues hinder agility since information flows slower, and fast reactions become more difficult. Overall visibility on the shop floor would be increased, if companies were using MES. Real-time information of status of resources and orders is lacking without MES, and this causes confusion both on the shop floor and upper levels within a company.

Regarding production control, many companies have problems with recordings such as time stamps. They should be done when job is started and finished. However, workers easily forget to do them or the start and finish are recorded at the same time. Also some of the workers tend to make recordings only at the end of the day. Recording the time stamps to the ERP is, according to some workers, simply too slow and arduous. Systematics is therefore clearly missing, and that is one reason why real-time information of the order status is also often missing.

4.1.2 Information management and transparency

Many challenges are identified related to communication both in the production network and between different departments inside an individual company. First of all, information transparency is an important issue and agility enabler, which needs to be defined here. It basically means that real-time information is visible and available to all parties that need the information.

Majority of the companies identified poor information transparency in their production network as a challenge. Through a common extranet, some OEMs are able to provide their closest suppliers and sub-contractors visibility to their own ERP-system. That way, for example, sub-contractors can pick production orders from OEM’s systems. However, none of the OEMs have any visibility to other direction. Therefore, two-directional visibility in the production network does not exist among companies. Communication is mostly managed by email and telephone. A few companies consider this as a challenge, as email or telephone may not reach everyone, who needs the information. Obviously, there is also a risk that information arrives too late to a person, who is not involved in the message chain. Lack of technical tools to increase the transparency in the production network is a challenge, which many companies are struggling with. Another problem in increasing the transparency, relates to information security. Above all, common rules and trust in the production network are needed in order to ensure information security. Due to lack of transparency in the production network, information of changes for instance supplier's delays may be got too late at the OEM's side.

About half of the companies mentioned to have problems regarding poor communication between different departments. This was especially challenging among OEMs. For example, production, sales and shipping departments work with different information, and this causes confusion. Products may be produced with wrong timing, as information of actual demand does not flow in real time between departments. Lack of integration of IT-systems used in different departments is a clear problem, which hinders the transparency between departments. If the IT-systems would be better integrated, less manual work in updating information between them would be needed. Lack of overall picture of the customer order status is a problem especially for some of the large OEMs manufacturing customized and complex products with long lead times. Since they manage huge amount of information in various systems, change management becomes challenging.

Some challenges related to Key Performance Indicators (KPIs) are considered to affect agility as well. Visualization of KPIs on the factory floor in real time can increase the overall visibility on how things are proceeding in production. This, in turn, can positively affect worker's motivation. Most of the large OEMs utilize different displays or notice boards to visualize the KPIs on the factory floor. However, companies without MES are unable to do that in real time. KPI reporting often requires manual work and takes too much time, since the data is often collected from different systems. Therefore, KPI data is updated rarely like once a month.

Several challenges occur related to usability and information exchange between IT-systems. It was repeatedly mentioned that the usability of current IT-systems could be better. A lot of manual work in updating information between various systems is needed. Information can be scattered over multiple IT-systems and it requires too much searching if IT-systems are not linked with each other. It is not productive time, if production worker has to spend time on searching the needed information from various sources. Interface problems between IT-systems are typical among companies. Those problems typically increase the need for various Excel-sheets. It was repeatedly mentioned that companies want to either decrease the amount of unconnected Excel-sheets or get totally rid of them.

4.1.3 Data collection and quality issues

One common challenge in data collection from the shop floor is the usage of paper documents. There is a significant risk that data only stays on the papers, and is never transferred to IT-system. Missing paper documents also cause unnecessary searching. If data from paper documents needs to be manually typed to IT-system, rapid reactions to changes and disturbances are clearly not possible. Usually data collected to paper documents, is later on not linked to product- or order information. Therefore, the data cannot be utilized to support production planning and control. Human contribution in data collection is problematic, as human easily forgets to make necessary recordings or make errors. About half of the companies collect data from different machines and robots automatically. A problem related to the utilization of this automatically collected data is that data goes to separate systems, which are not linked with the needed IT-systems.

Several challenges regarding quality issues were identified. A couple of companies have a relatively simple problem that in some cases workers are unaware of acceptable quality. This naturally creates challenges for quality assurance. In many companies, quality defects are not stopped on the production line immediately as they occur. Instead, they are usually fixed at the end of the line in a specific repair station. This is against Lean principles, and does not support the elimination of quality problems. Another quality related challenge, which was actually identified by the research group, is a lack of quality culture. For instance, some workers may not report about quality problems as they take it as blaming their working colleagues. Lack of systematics in recording quality problems is considered problematic in most of the companies. Some quality problems are handled on the factory floor without reporting about them to any IT-system. For production worker, it may be faster to just fix a small quality problem and not record about it, especially if recording is time-consuming.

4.1.4 Lean practices and continuous improvement

Not all challenges related to Lean practices and their usage is discussed here. Instead, the focus is on reviewing Lean issues, that based on literature review can support agility. Concerning waste reduction, which is an essential element in both Lean and Agile manufacturing, many companies are holding excessive inventories. One reason for holding inventories is lack of trust to company's own and supplier's delivery reliability. As was mentioned earlier, lack of transparency in the production network decreases OEM's possibilities to react timely on disturbances such as delays in component supplies from suppliers. Inventories easily hide that kind of problems. Related to inventory management, some companies have problems with faulty inventory balances. For instance, workers retrieve new components from the inventory without making a record to the ERP. This is a typical situation especially when workers need to hurry because of a rejected product.

Short lead times should be an obvious goal for companies that want to become more agile. Majority of the companies aim to systematically reduce their lead times. However, most sub-contractors prefer manufacturing large batches. Long setup times typically favour larger batches. Unawareness of non-value adding activities in lead time can also cause challenges for lead time reduction. Only a few companies had utilized value stream analysis to identify wasteful activities in their production.

Many companies have challenges related to continuous improvement, which is considered as an important agility enabler. Workers should be engaged more actively to the continuous improvement. They should be given more responsibility in development projects on the factory floor, and their ideas should be utilized more systematically. Building a culture of continuous improvement is still challenging, especially because some workers are strongly sticked to old way of doing things. Majority of the companies are simultaneously running many development projects, but continuous improvement should not be an isolated project. Instead, it should be active all the time, and workers must be aware of it.

4.1.5 Worker's skills, flexibility and motivation

In agile companies, workers must be multi-skilled in order to have capabilities to perform various tasks at different work phases as need occurs. Lack of systematic job rotation is a challenge hindering the multi-skills of workers especially among sub-contracting companies. A further challenge related to job rotation is that some workers are not willing to practise it. Developing worker's skills also demands training, but lack of time resources for training is a common challenge among companies. Training should always be planned to improve certain skills. Therefore, a clear strategy for developing worker's skills is needed. This kind of strategy is still missing within most of the companies. Above-mentioned challenges strongly hinder the flexibility of workers. A couple of production managers were hoping that their workers would be more self-organizing on the shop floor. This means that workers should be able to independently identify change situations when they need to move between machines or work stations to help working colleagues. In some cases a team leader is often needed to guide workers.

Worker's motivation level affects significantly their performance. Lack of feedback in some companies was mentioned as a challenge that can reduce motivation. Especially among production workers it was noted that leaders should give more positive feedback, which would increase their motivation. Lack of feedback can have effects on worker's decision making, meaning that they make wrong decisions for the whole. Spoken feedback from leaders is not enough, but also KPIs and IT-systems should provide real-time feedback on the shop floor. Processing of the initiatives in many companies is not systematic, which can also decrease worker's motivation. If workers have feeling that making initiatives does not lead anywhere, they easily stop making them.

4.2 Interconnections between challenges

This chapter presents interconnections between the identified challenges by utilizing the relationships map, which visualizes the results of the cause-effect analysis. As the relationships map in figure 10 illustrates, each challenge is connected to at least one different challenge. Each arrow is leaving from a challenge, which is a cause, and ending to another challenge, which is an effect. The coloured arrows are utilized to avoid confusing arrows with each other. The challenges dealing with similar issues are located close to each other. For example, challenges related to quality issues are located next to each other in the bottom row. However, some challenges are difficult to categorize, hence their location in the map is coincidental.

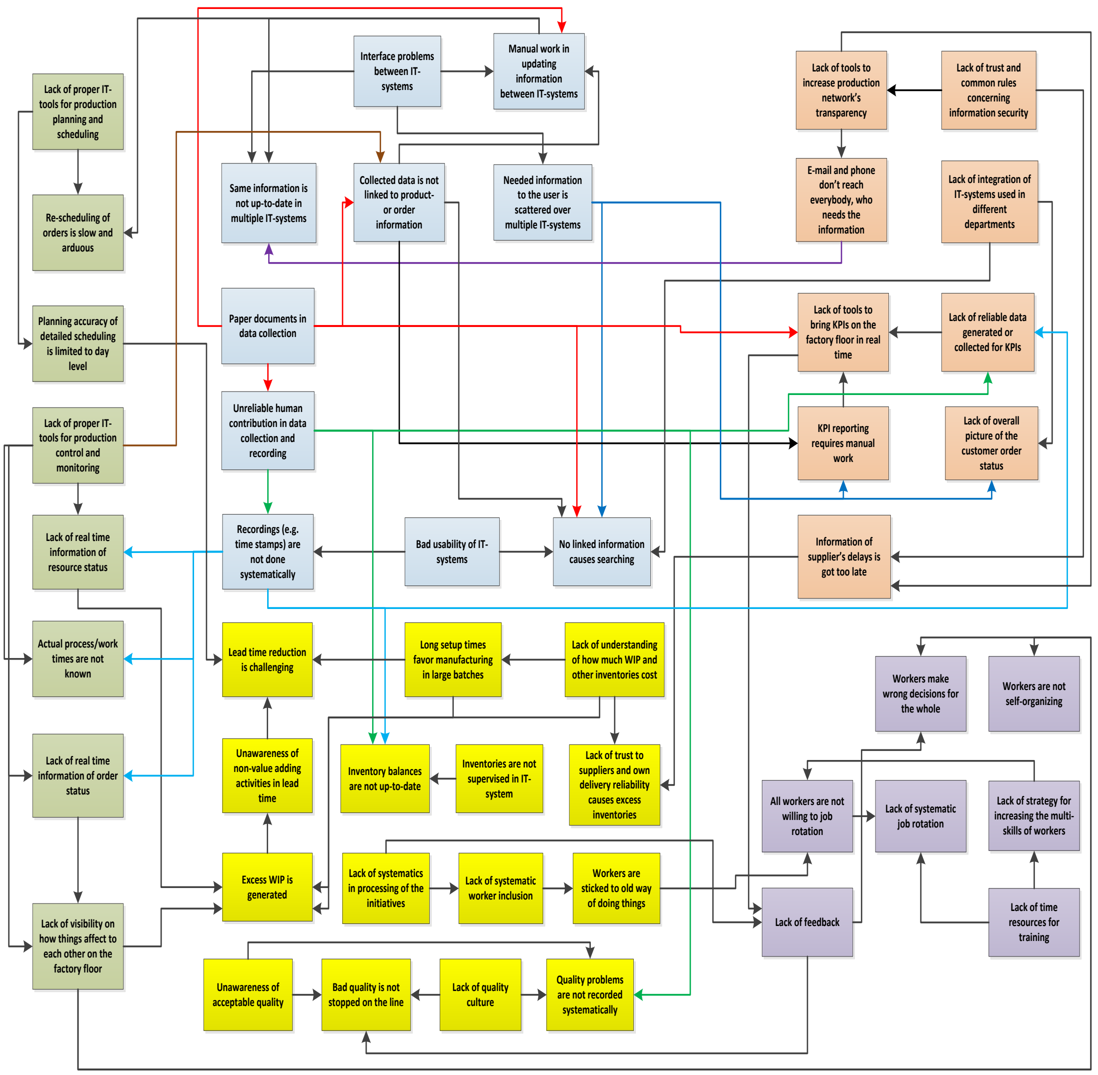

Figure 10: Relationships map including the interconnections between challenges.

The main purpose of the relationships map is to identify the most critical challenges and increase understanding on how different kind of challenges are generated. It has to be noted, that reason for the existence of an individual challenge can be caused by multiple smaller problems that were not identified in the interviews. Analysed cause-effect relationships are still relatively generic despite different company types. Each interviewed company can identify those challenges that are relevant for them and follow the interconnections drawn in the map.

As the relationships map indicates, amount of direct effects originating from an individual challenge is varying from zero to five. The higher the number, the more critical the challenge is based on this analysis. In some cases, challenges having less effects can still be considered critical. For example, the challenge *"lack of proper IT-tools for production planning and scheduling"*, which refers to lack of APS systems, affects only two other challenges included in the map. However, implementing an APS system enables faster and easier re-scheduling of orders. Simultaneously, planning accuracy of detailed scheduling can be increased. Hence, solving that challenge, two other challenges are solved. Similarly, lack of time resources for training connects to two other challenges. In this case, lack of systematic job rotation cannot be solved only by solving the time resource problem, as willingness of workers to job rotation remains another problem. These examples indicate that the number of interconnections must be considered at some level, but the type of a challenge counts as well.

Some challenges in the map have quite obvious causes. For instance, if a company is struggling with the challenge *"quality problems are not recorded systematically"*, three options for causes are suggested in the map. This case is illustrated in figure 11.

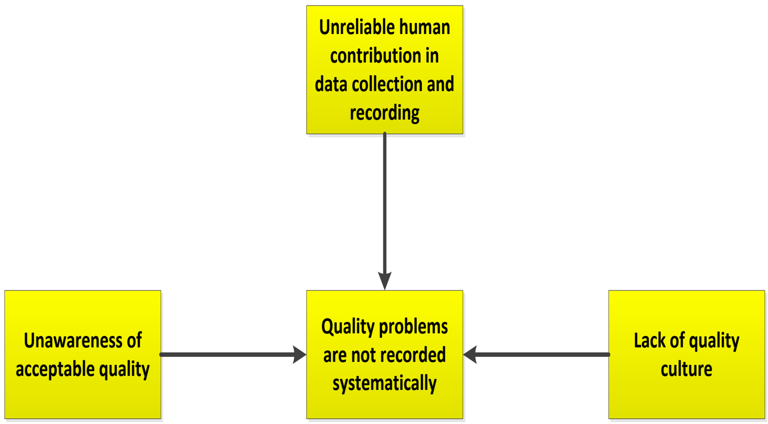

Figure 11*: Possible causes of a quality related challenge.*

The cause can be *"unawareness of acceptable quality"* or *"lack of quality culture"* or *"unreliable human contribution in data collection and recording"*. It is also possible that all these three problems together are causing the challenge. The solution can be relatively simple if the company identify that acceptable quality is not defined accurately. A production worker cannot identify all quality problems if the quality requirements are inadequate. On the other hand, if the problem lies in the culture, it can be more difficult to solve. Solving all the three problems most probably leads to more systematic recording of quality problems.

4.3 Analysis of root causes

This chapter focus on analysing root causes and their effects on connected challenges. As can be noted from the relationships map, certain challenges have direct effects on four or five other challenges. Those challenges are considered to be possible root causes in this context. Two challenges are clearly root causes, as they have five direct effects on other challenges, and they are not caused by any other challenges. First, the effect chains of a root cause *"lack of proper IT-tools for production control and monitoring"* are presented in figure 12.

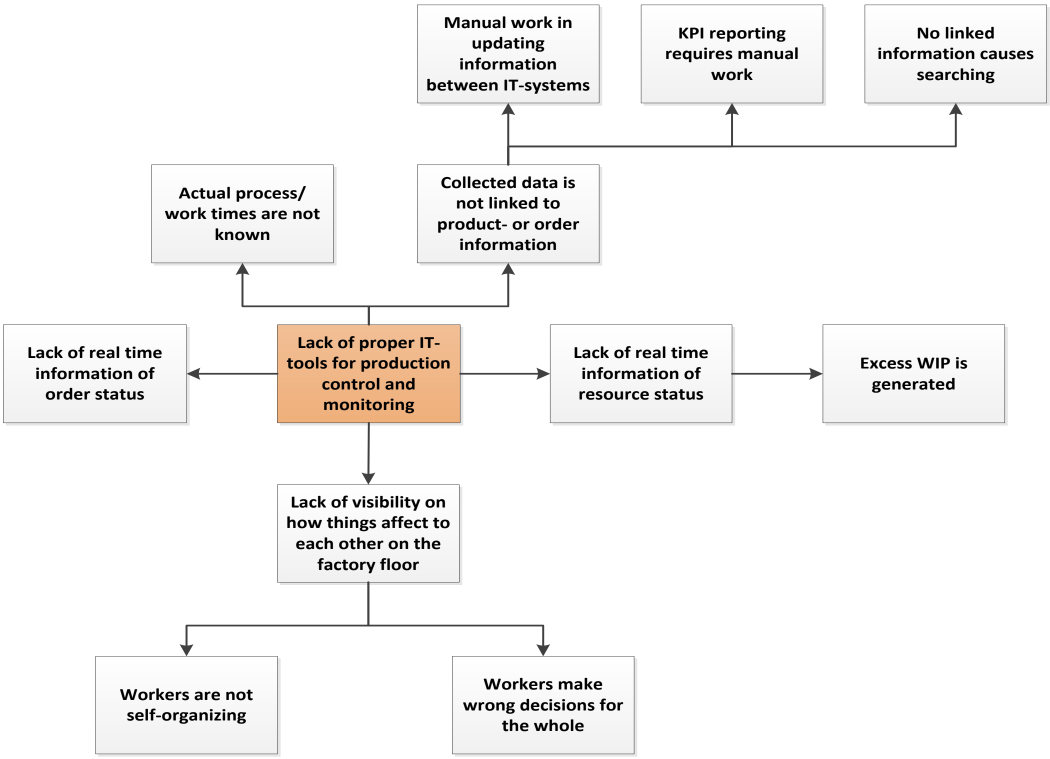

***Figure 12**: Effect chains of the first root cause.*

The first root cause refers to the lack of MES functionality, which is a major challenge in most of the companies. Two "levels" of effects are included in this analysis. This means, that for example the challenge *"excess WIP is generated"* belongs to second level, as it is not marked as a direct effect originating from the root cause. The figure 12 illustrates that by solving this root cause, companies are in better position to tackle various other challenges related to different type of issues. For example, improved production control and monitoring through MES enables the collection of history data concerning process/work times, and it decreases manual work regarding information updating. MES increases the overall visibility on the factory floor, as status information of resources and orders is provided in real time. Through increased visibility, production workers may become more self-organizing in moving flexibly between work phases.

Second challenge, which is obviously a root cause, is the usage of paper documents in data collection. Just like the previous root cause, this one also has five direct effects on other challenges, as shown in figure 13.

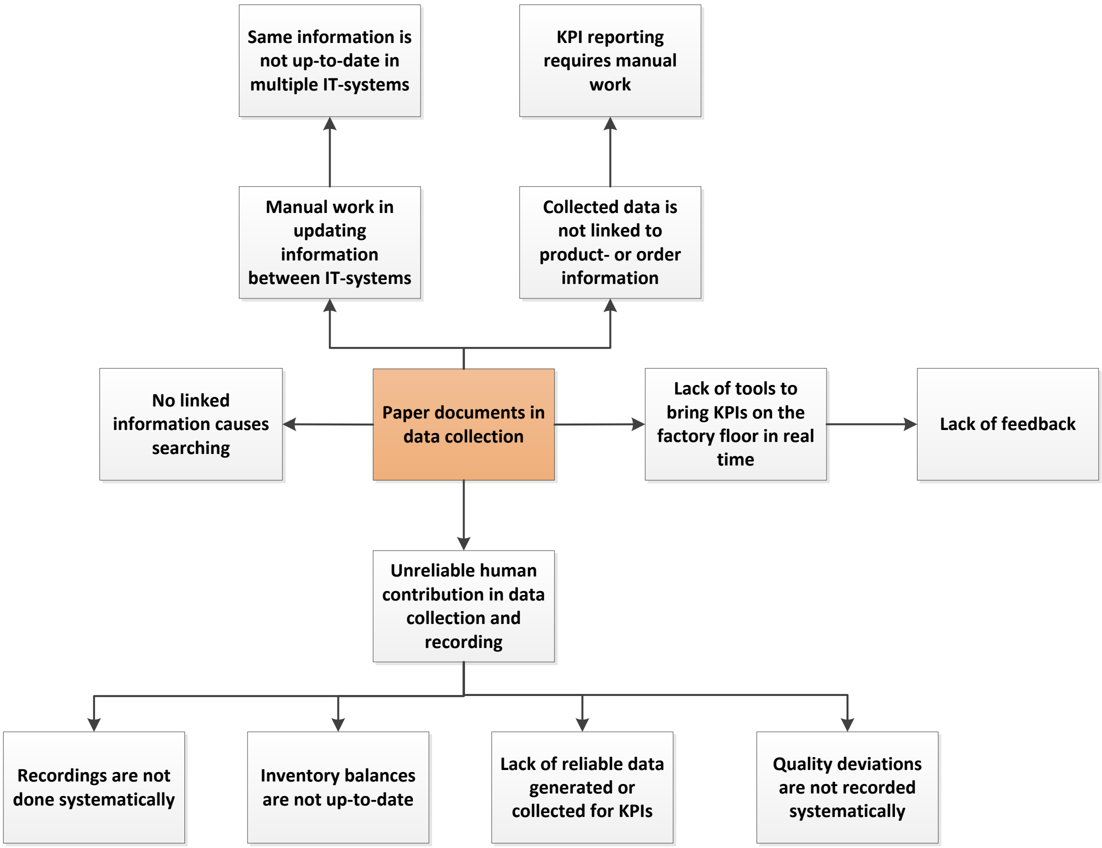

Figure 13: *Effect chains of the second root cause.*

Paper documents in data collection slow down information flows and affect negatively many issues related to information management. They cause unnecessary searching and manual typing of data to the IT-system. If data for certain KPIs is collected with paper documents from the factory floor, it is clear that the KPI data cannot be brought on the factory floor in real time. Therefore, feedback to the production workers through KPIs is not provided in real time. Lack of linked information in this case means, that collected data is stored in different databases and locations. Some paper documents may be lost on the factory floor, whereas others may be spread in offices. From the viewpoint of production worker, searching for work instructions may require opening folders or checking IT-systems. Collecting data to paper documents naturally means that human contribution is needed. This, in turn, leads to four different challenges. Therefore, a challenge *"unreliable human contribution in data collection and recording"* is discussed next.

Although the usage of paper documents as a root cause has a direct effect to human contribution, the latter is still regarded as a different root cause in the relationships map. Namely, unreliable human contribution can also exist without the previous root cause.

In other words, elimination of paper documents from data collection does not remove the risk that human for instance forgets to make recordings. The third root cause and its effects are visualized in figure 14.

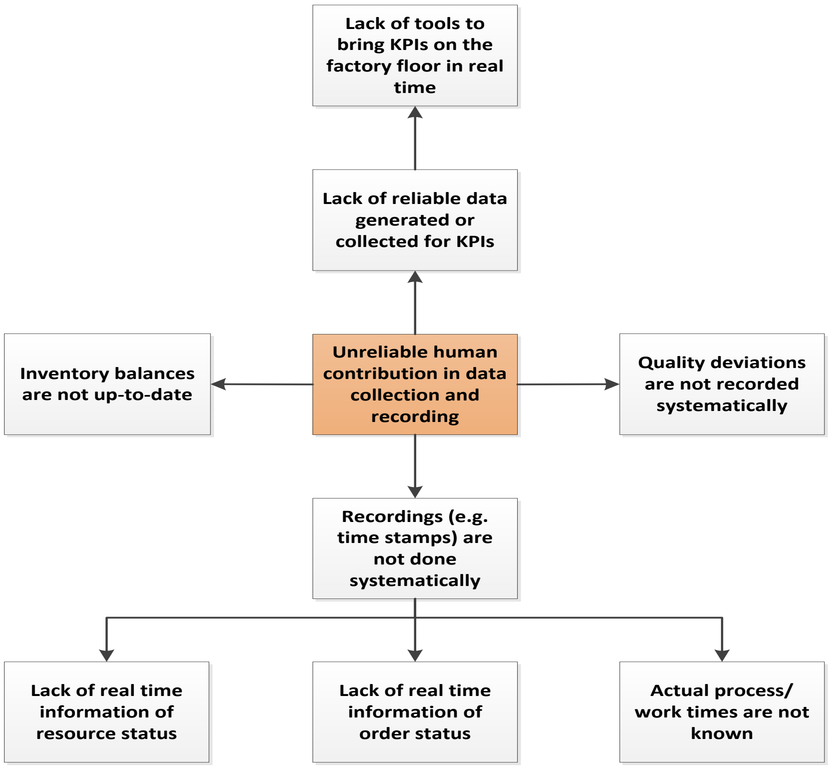

Figure 14: *Effect chains of the third root cause.*

Concerning recording the time stamps, unreliable human contribution remains problematic. Workers should record the time stamps, when they start and finish a job. Depending on the duration of a job, forgetting the time stamps can easily lead to a situation, where nobody knows about the actual status of the resources or orders. Simultaneously, information about the duration of jobs is not collected. These challenges were also affected by the first identified root cause, namely lack of MES functionality. Faulty inventory balances can also be caused by human, if recordings are not done immediately when material is picked from the storage. Related to the KPI data, part of it may be unreliable or totally missing especially if the data is generated from recordings made by human.

The fourth and last identified root cause is *"interface problems between IT-systems"*. This root cause affects directly three challenges and indirectly additional three challenges, as shown in figure 15. Since IT-systems used for different purposes lack capabilities to communicate together, information flow is non-existent. Information is often scattered over multiple IT-systems, and it is time-consuming to the user to search for the needed information. Scattered information further causes a problem that the overall picture of the customer order status is lacking. This is especially challenging among companies delivering complex project-based products, which have lead times of several months. In those cases, information is usually managed in multiple IT-systems, and changes in one system are not transferred to all the needed systems in real time. Due to interface problems, up-to-date information is not available, and updating information typically requires manual error prone typing.

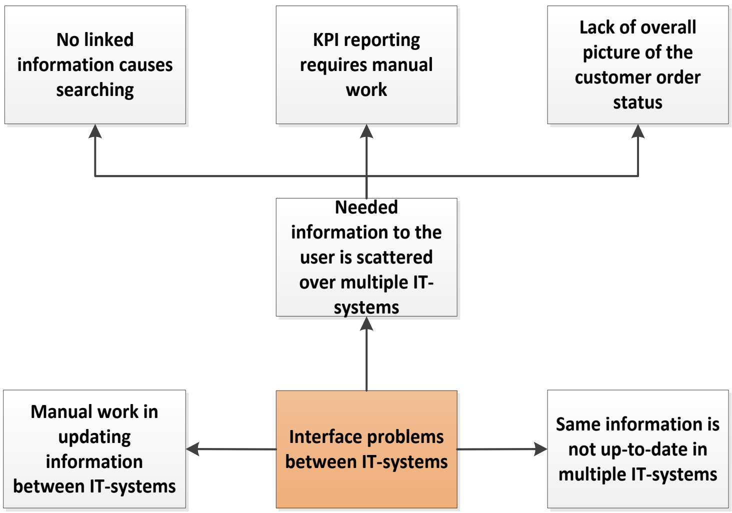

Figure 15: *Effect chains of the fourth root cause.*

As the four identified root causes and their effect chains indicate, many effects were either directly or indirectly caused by more than one root cause. This means, that focusing only on solving one root cause is not enough. Besides these root causes, other challenges not included in the above visualized effect chains are causing problems as well. However, analysis of root causes provides certain guides for prioritizing actions needed for solving challenges.

4.4 Actions for improving agility

In this chapter, actions for solving identified challenges are proposed. The interconnections visualized in the relationships map as well as the identified root causes are taken into account, while evaluating the importance of actions. Above all, the aim is to propose actions for the most critical challenges. Those actions will help reducing the number of challenges, thus improving agility among companies. For certain challenges, practical actions can be proposed quite easily. This applies particularly to the challenges described with lack of something. For instance, lack of strategy for increasing worker's skills is a challenge, which is easy to turn to a clear action.

Proposed actions are classified to action map based on two criteria. Firstly, priority of actions can be roughly defined based on the information got from the relationships map. Secondly effort required in implementing actions is taken into account. Effort in this case means costs and time resources that are needed. It must be noted that quantitative values for costs and time are not provided, since they are difficult to define in this context. Instead, both criteria are divided to low, medium and high classes. The type of individual action is varying quite much. Some actions are clearly related to technical solutions, whereas other actions deal with softer issues such as cultural improvements. It depends on individual company whether the priority or the implementation effort is the guiding criteria for evaluating the correct order to start implementing actions. The action map is illustrated in figure 16.

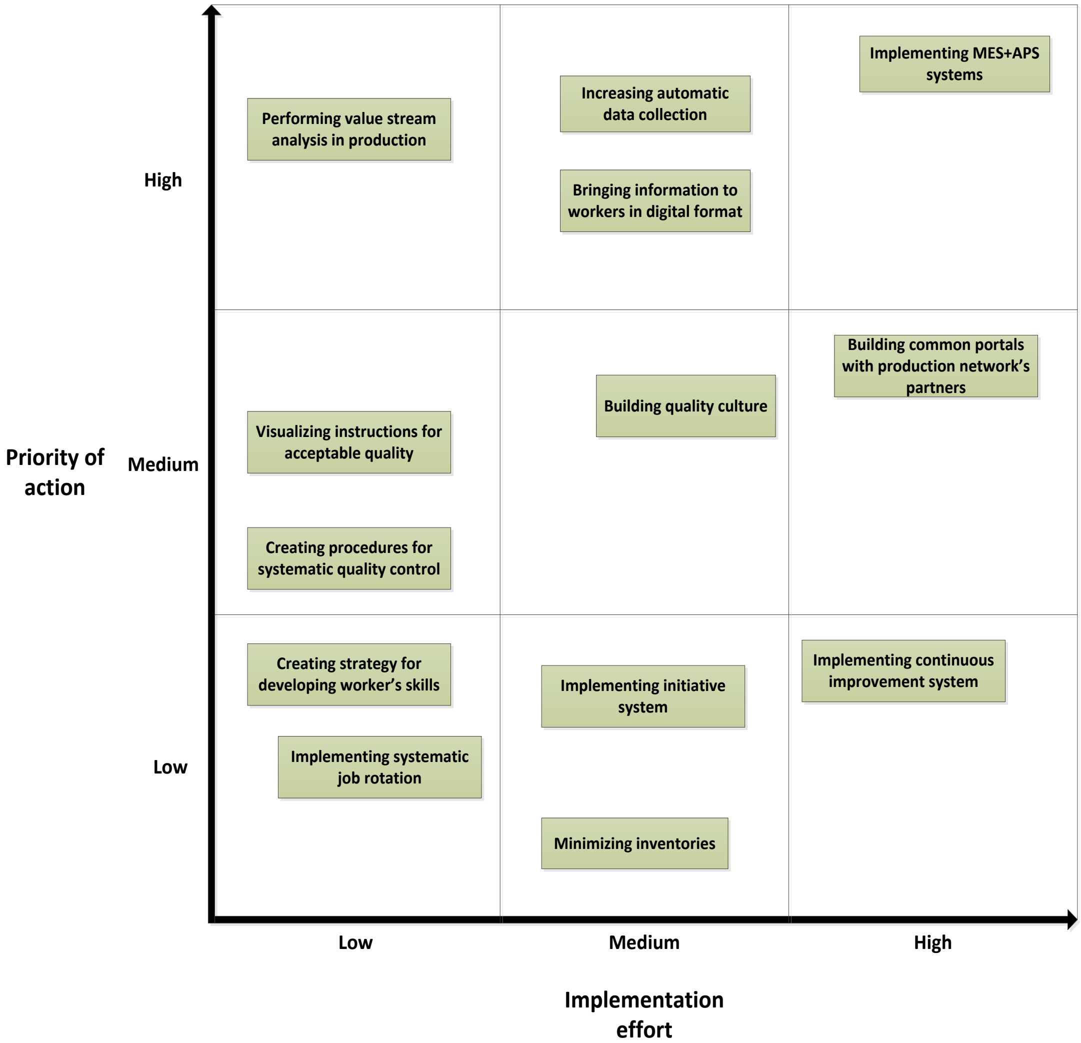

Figure 16*: Action map.*

Both OEMs and sub-contractors can utilize the action map in identifying correct actions for their challenges. Differences between OEMs and sub-contractors regarding identified challenges were relatively small, therefore prioritizing actions separately to above mentioned company types is not necessary. However, for example a small sub-contractor may find it more beneficial to start from actions that do not require huge implementation effort. On the other hand, a large OEM may be capable of starting from actions that call for higher implementation effort.

Proposed actions

As the action map illustrates, actions related to information management are mainly located in upper part of the map, whereas most of the operational and cultural improvement actions are given lower priority. Based on the collected interview material and the conducted cause-effect analysis, implementation of MES and APS systems can significantly reduce the number of challenges, thus this action is of high importance. As human contribution should be minimized in data collection, a relevant action is to increase automatic data collection. Similarly, minimizing human contribution is made easier with correct manufacturing IT-systems in place. As the usage of paper documents on the factory floor should be decreased, all the information needed by workers should be presented in digital format. Tablets and smart phones, for instance, could be used to display work orders, work instructions and drawings to workers. This would most probably reduce the amount of time spent for searching for information.

For increasing information transparency in production network, common portals between network's partners should be built. Some of the large OEMs mentioned in interviews that they are planning to build supplier portals in near future. As has been mentioned before, the transparency between OEMs and their sub-contractors in production network is typically one-directional. In ideal case, two-directional transparency would be possible. However, it may require a lot of work. Companies have to consider how the needed information can be transferred fast and with little effort between the ERP and portal. In order to ensure that information exchange happens in real time, it is essential that needed systems and portals are well integrated.

For solving challenges related to quality issues, three actions are proposed. Firstly, building a quality culture should be the first step within these three actions. It probably requires a lot of time resources, since training for the whole personnel is needed. It is of high importance that workers are engaged to report about quality problems immediately when they are noticed. Notifying work colleagues about bad quality should not be considered as a negative thing. The whole personnel from top management to factory floor workers should have similar image of the importance of high quality. Secondly, unawareness of acceptable quality is solved quite easily by defining clear instructions for acceptable quality. The instructions should be visualized with displays at each work station or machine. Thirdly, clear procedures should be created to make quality monitoring more systematic. With these procedures, workers are guided to make for example the recordings in a certain defined way.

Regarding worker's skills, companies should first make sure that they have a strategy for developing skills. Without a strategy, for instance job rotation is most probably not practised systematically. Some companies are already familiar with job rotation, but systematics is still missing. Job rotation should not be practised randomly. Instead, it should be practised on a regular basis. With these two relatively simple actions, companies would improve their agility by having multi-skilled workers capable of rapidly change between work phases. In order to engage workers in development tasks, one proposed action for bringing their ideas forward is to implement initiative system. However, it may be challenging to make sure that the system is actually producing ideas. Therefore, managers need to focus on giving enough feedback about all the produced initiatives. Otherwise, workers probably stop making initiatives. Companies should also implement continuous improvement system, which supports the progress of all improvements systematically. This action again requires the involvement of the whole personnel, therefore required effort is high.

One tool for supporting systematic lead time reduction is value stream analysis. It helps identifying wasteful activities and problem areas where to focus on. Through value stream analysis, production's lead time can be divided into value-added-time and non-value-added time. In the action map, value stream analysis is given high priority, since it would be a good starting point for all kind of companies. It can be performed with relatively little effort. Furthermore, it can be performed regularly to evaluate how other actions are producing improvements in company's performance.

As was mentioned earlier while discussing identified challenges, oversized inventories are problematic among companies. Minimizing inventories should not be first actions for improving agility, since many companies are struggling with delivery reliability problems. Implementing actions for solving quality related issues and improving production network's transparency will create certain readiness for companies to operate with smaller inventories. Through faster information flow in production network, delivery reliability can be improved, and less need for excess inventories exists.

Benefits achieved by implementing proposed actions

The proposed actions will result in notable benefits for companies implementing them. Some important benefits are collected to below list.

- Information of changes available for all actors in real time
- Less confusion on the factory floor during change situations
- Increased visibility on the factory floor
- Less time spent in searching for information
- Less manual typing required in updating information
- Workers can concentrate on value-adding work
- Faster and more reliable data collection
- Increased visibility in production network
- Information of upcoming deviation comes in real time
- Higher motivation
- More improvement ideas from workers
- Less work-related stress

- Multi-skilled and self-organizing workers
- Shorter lead times
- Higher quality
- Less capital tied up in excess inventories

Together the above mentioned benefits indicate that companies can better survive under continuous changes, thus they possess higher agility. It must be noted that above mentioned benefits provide just an overview. Various additional benefits could be achieved as well with proposed actions. It can also depend on individual company, which benefits become the most visible while implementing proposed actions.

5. CONCLUSIONS

The overall objective of the thesis was to create a roadmap, which helps Finnish manufacturing companies can utilize in identifying and prioritizing actions that are needed in order to improve agility. The first sub-objective aimed on investigating practices, characteristics and tools that can be considered as enablers of agility from a manufacturing company point of view. Based on the literature review, enablers of agility can be comprised of pure technical tools as well as softer characteristics and practices. On operational level, technical solutions such as flexible and reconfigurable manufacturing systems support rapid reactions to changes. Concerning manufacturing IT-systems, MES and APS-functionalities are beneficial to ensure that real-time information flows fast between different actors within a manufacturing company. Important enabler connected to supply chain agility is information transparency between supply chain's partners. Sharing relevant information in real-time through common systems improves agility in the chain. Related to worker's characteristics, self-organizing, multi-skilled and highly motivated workers support agility on the factory floor. Lean manufacturing elements such as systematic waste reduction and continuous improvement have also positive impact on agility. Above listed enablers indicate that agility can be supported and improved by focusing on various types of areas.

The second sub-objective was to identify challenges that Finnish manufacturing companies are having related to agility. The collected interview material from 25 companies revealed various challenges, most of them connected to the field of manufacturing operations management. OEMs and sub-contractors are mainly facing similar challenges, even though few challenges are more dependent on the company type. For instance, communication gaps between different departments were causing problems especially for large OEMs, whereas the lack of systematic job rotation was a challenge within most sub-contractors. Regarding production planning and control practices and tools, most of the companies are not using correct IT-systems in production planning and control to support rapid reactions to changes. In data collection from the factory floor, the usage of paper documents and lack of systematics in recordings were critical challenges. The lack of information transparency in production network was a major challenge hindering effective and fast information flow. Quality defects were not recorded systematically and cultural issues were not supporting the elimination of quality problems. Concerning worker's skills, the lack of strategy for developing skills was problematic. Oversized inventories and unawareness of non-value adding activities were examples of challenges related to Lean issues. Altogether 50 challenges affecting agility were identified for further analysis.

The third sub-objective focused on finding out the most critical challenges hindering agility in Finnish manufacturing companies and proposing actions for solving the challenges. Interconnections between the identified challenges were defined with cause-effect analysis and the results were visualized in the relationships map. Cause-effect analysis helped to identify four critical challenges, which were considered as root causes for several other challenges. The lack of proper manufacturing IT-tools; usage of paper documents in data collection; unreliable human contribution in data collection; and interface problems between IT-systems were identified as root causes. However, the number of interconnections between challenges was not varying much. Therefore, a clear priority order for solving all the challenges was not defined. Still, priority order for the most critical challenges was more obvious.

Finally, after the challenges were analysed, actions for improving agility were proposed. The proposed actions were classified into action map based on their priority and implementation effort. Above all, the aim was to propose actions for solving critical challenges hindering agility. The action map indicates that certain actions require investments in new technologies, whereas some actions focus on creating new strategies and changing cultural issues. For example, implementing an MES, and building quality culture demand different kind of capabilities from companies.

As main results, this thesis produced two visualized maps, which can be utilized in identifying and prioritizing actions while thriving towards higher agility. Firstly, the relationships map presenting the interconnections between different challenges increases understanding on how problems can be generated and connected to each other. An individual manufacturing company can identify critical challenges from the map and follow the defined interconnections. However, the relationships map only presents the challenges that emerged from the interviews. Therefore, the map is unable to provide information of all possible challenges hindering agility among manufacturing companies. Instead, it presents major challenges that are mostly related to manufacturing operations management. Secondly, the action map proposes 13 practical actions that manufacturing companies can start to implement, when they identify needs to improve their agility. Together, these two maps serve as roadmaps towards agility for Finnish manufacturing companies.

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